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(54) Title: OPTICAL FIBER FOR LIGHT AMPLIFIER

(57) Abstract

An optical fiber used for an optical amplifier, which is formed by doping glass with rare-earth ions. Both praseodymium ions ( $Pr^{+3}$ ) and erbium ions ( $Er^{+3}$ ) are used as the rare-earth ions, and the glass is a fluoride glass or a sulfide glass. The optical fiber can be used at both wavelengths of  $1.3 \mu m$  and  $1.55 \mu m$ . The light amplification efficiency of an optical amplifier made of the optical fiber can be improved compared to an optical amplifier formed of only  $Pr^{+3}$  or only  $Er^{+3}$ .

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## OPTICAL FIBER FOR LIGHT AMPLIFIER

### Technical Field

The present invention relates to optical fibers for use in a light amplifier,  
5 and more particularly, to an optical fiber for use in a light amplifier which can  
be used at wavelengths of both 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ .

### Background Art

The wavelength of light used in optical communications has been  
10 shifted from a wavelength of 1.3  $\mu\text{m}$  to a wavelength of 1.55  $\mu\text{m}$ . In general, praseodymium ions ( $\text{Pr}^{+3}$ ) which are used to dope an optical fiber, are used to amplify an optical signal having a wavelength of 1.3  $\mu\text{m}$  while erbium ion ( $\text{Er}^{+3}$ ) which are used to dope an optical fiber, are used to amplify an optical signal having a wavelength of 1.55  $\mu\text{m}$ .

15 U.S. Patent No. 5,486,947 discloses an optical fiber for use in an optical amplifier, which are capable of operating with optical sufficient optical gain at the 1.3  $\mu\text{m}$  wavelength. The optical fiber is a fluoride glass optical fiber containing rare earth metal ions in a core glass, wherein the refractive index difference between the core and a cladding layer is above 1.4%, and the glass  
20 contains lead difluoride ( $\text{PbF}_2$ ) in a proportion of 25 mol % or less based on the total composition for forming the glass.

Now, both wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$  are used in many optical communications related fields. Thus, different parts which are suitable for each wavelength, are required to construct an optical circuit, so that  
25 development cost increases in addition to switching cost for switching the wavelengths.

### Disclosure of the Invention

An object of the present invention is to provide an optical fiber for use  
30 in an optical amplifier, which can be used for both the 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$  bands.

According to an aspect of the present invention, there is provided an optical fiber for an optical amplifier, which is formed by doping glass with rare-earth ions, wherein both praseodymium ions ( $Pr^{+3}$ ) and erbium ions ( $Er^{+3}$ ) are used as the rare-earth ions, and the glass is a fluoride glass or a sulfide glass.

5 Preferably, the content of  $Pr^{+3}$  is 100~1000 ppm and the content of  $Er^{+3}$  is 100~5000 ppm. If the  $Pr^{+3}$  and  $Er^{+3}$  content is outside the above range, light amplification efficiency is undesirably lowered. Also, the mixing ratio of  $Pr^{+3}$  to  $Er^{+3}$ , by weight, may be between 1:1 and 1:3. If the ratio of  $Pr^{+3}$  to  $Er^{+3}$  exceeds the above ratio, fluorescence emission quantity at the wavelength of 10 1.55  $\mu m$  is decreased. Conversely, if the ratio of  $Pr^{+3}$  to  $Er^{+3}$  is less than the above ratio, the amplification at the wavelength of 1.3  $\mu m$  unfavorably decreased.

#### Brief Description of the Drawings

15 FIG. 1 shows the fluorescence emission spectrum at wavelengths of 1.3  $\mu m$  and 1.55  $\mu m$  according to the amount of  $Er^{+3}$  in optical fibers, when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping glass made of  $Ge_{29}As_8Ga_1S_{62}$  with  $Pr^{+3}$  and  $Er^{+3}$ , wherein the fluorescence emission at the wavelength of 1.3  $\mu m$  is caused by the 20 electron transition of  $Pr^{3+}$  from the  $^1G_4$  level to the  $^3H_5$  level in  $Pr^{+3}$  doped fibers, and that at the wavelength of 1.55  $\mu m$  is caused by the transition  $^4I_{13/2} \rightarrow ^4I_{15/2}$  in  $Er^{3+}$  doped fibers;

FIG. 2 is a graph showing the fluorescence lifetime of  $Pr^{+3}$  at the  $^1G_4$  level and of  $Er^{+3}$  at the  $^4I_{13/2}$  level and  $^4I_{11/2}$  level according to the amount of 25  $Er^{+3}$  in optical fibers, when a laser beam having a wavelength of 980 nm is irradiated onto an optical fiber which is formed by doping a  $Ge_{29}As_8Ga_1S_{62}$  glass with  $Pr^{+3}$  and  $Er^{+3}$ ;

FIG. 3 is a diagram illustrating energy transfer between  $Pr^{+3}$  and  $Er^{+3}$  ions;

30 FIG. 4 shows the fluorescence emission spectrum at the wavelength of 1.3  $\mu m$  by the electron transition of  $Pr^{+3}$  from the  $^1G_4$  level to the  $^3H_5$  level when a laser beam having a wavelength of 1020 nm is irradiated onto an optical fiber which is formed by doping a  $Ge_{29}As_8Ga_1S_{62}$  glass with  $Pr^{+3}$ ;

FIG. 5 shows the fluorescence emission spectrum at the wavelength of  $1.55 \mu\text{m}$  by the electron transition of  $\text{Er}^{3+}$  from the  $^4\text{I}_{13/2}$  level to the  $^4\text{I}_{15/2}$  level when a laser beam having a wavelength of  $980 \text{ nm}$  is irradiated onto an optical fiber which is formed by doping a  $\text{Ge}_{29}\text{As}_8\text{Ga}_1\text{S}_{62}$  glass with  $\text{Er}^{3+}$ , and

5 FIG. 6 shows the fluorescence emission spectrum at the wavelengths of  $1.3 \mu\text{m}$  and  $1.55 \mu\text{m}$  according to the amount of  $\text{Pr}^{3+}$  in optical fibers, when a laser beam having a wavelength of  $980 \text{ nm}$  is irradiated onto an optical fiber which is formed by doping a  $\text{Ge}_{29}\text{As}_8\text{Ga}_1\text{S}_{62}$  glass with  $\text{Pr}^{3+}$  and  $\text{Er}^{3+}$ , wherein 10 the fluorescence emission at the wavelength of  $1.3 \mu\text{m}$  is due to the electron transition of  $\text{Pr}^{3+}$  from the  $^1\text{G}_4$  level to the  $^3\text{H}_5$  level, and that at the wavelength of  $1.55 \mu\text{m}$  is due to the electron transition of  $\text{Er}^{3+}$  from the  $^4\text{I}_{13/2}$  level to the  $^4\text{I}_{15/2}$  level.

#### Best mode for carrying out the Invention

15 The present invention provides an optical fiber for use in a light amplifier, which can be used at wavelengths of both  $1.3 \mu\text{m}$  and  $1.55 \mu\text{m}$ , by using a laser beam having a wavelength of  $980 \text{ nm}$  as a light source for exciting an optical fiber formed of  $\text{Pr}^{3+}$  and  $\text{Er}^{3+}$ . In the present invention, the term "fibers" refers to shapes with a wide range of diameters, not merely thin 20 fibers. For example, a fiber may have diameter of 5 to 100mm. In the present invention, the fiber contains  $\text{Pr}^{3+}$  and  $\text{Er}^{3+}$ , wherein the maximum absorption peak of  $\text{Er}^{3+}$  in a laser beam having wavelength  $980 \text{ nm}$  is at the  $^4\text{I}_{11/2}$  level. In this case, two ions are simultaneously excited, so that  $\text{Pr}^{3+}$  emits 25 fluorescence at  $1.3 \mu\text{m}$  and  $\text{Er}^{3+}$  emits fluorescence at  $1.55 \mu\text{m}$ . In particular, as shown in FIG. 3, the fluorescence lifetime of  $\text{Pr}^{3+}$  at the  $^1\text{G}_4$  level is elongated due to the energy transfer from  $\text{Er}^{3+}$ , so that light amplification efficiency is improved compared to a conventional optical fiber containing only  $\text{Pr}^{3+}$ .

30 Preferably, in the present invention, a fluoride or sulfide glass is used to minimize lattice vibration relaxation of  $\text{Pr}^{3+}$  from the  $^1\text{G}_4$  level to  $^3\text{F}_4$  level. The fluoride glass may be a ZBLAN glass which is a fluoride containing zirconium (Zr), barium (Ba), lanthanum (La), aluminum (Al) and sodium (Na), and the sulfide glass may be a germanium-arsenic-gallium-sulfur (Ge-As-Ga-

S) or Ge-As-S glass. Here, using the sulfide glass can further minimize the lattice vibration relaxation of  $\text{Pr}^{+3}$  from the  ${}^1\text{G}_4$  level to the  ${}^3\text{F}_4$  level compared to the case of using the fluoride glass. However, using the fluoride glass rather than a sulfide glass generally makes the manufacture of optical fiber easier.

5 In order to maximize the light amplification efficiency at both wavelengths of  $1.3 \mu\text{m}$  and  $1.55 \mu\text{m}$ , the mixing weight ratio of  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$  is adjusted to be between 1:1 and 1:3.

10 Hereinafter, the present invention will be described using the following examples. However, these examples are merely illustrative and the present invention is not limited thereto.

#### Comparative Example 1

15 Ge, As, Ga and S having a purity of 99.999% or more, were weighted in an atomic ratio of 29:8:1:62 in a glove box where the content of hydroxy (OH) group and oxygen was maintained to be 10 ppm or less, and Pr metal powder was added in amount of 300 ppm to give the  $\text{Pr}^{+3}$ .

20 After filling a  $\text{SiO}_2$  test tube with the above composition, the test tube was left under a vacuum condition of 0.1 mTorr for a predetermined period of time. Then, the test tube was made airtight by sealing it with an oxy-propane flame.

25 Following this, the test tube was put into a rocking furnace such that the composition comprised in the test tube was completely mixed, and the resultant was kept at  $950^\circ\text{C}$  for 12 hours. Then, the test tube was quenched in air, and heated in a furnace which was set at  $400^\circ\text{C}$  for 1 hour. After the heating process, the test tube was slowly cooled to room temperature and broken into pieces, resulting in an optical fiber formed of a  $\text{Pr}^{+3}$ -doped sulfide glass of  $\text{Ge}_{29}\text{As}_8\text{Ga}_1\text{S}_{62}$  in which the amount of lattice vibration relaxation was slight. The optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished.

30 Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 1017 nm as a source of light excitation. At this wavelength,  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level showed a maximum light absorption.

As a result, the fluorescence emission at a wavelength of 1.3  $\mu\text{m}$ , which was caused by electron transition of  $\text{Pr}^{+3}$  from the  $^1\text{G}_4$  level to  $^3\text{H}_5$  level, was observed (see FIG. 4), and the fluorescence lifetime was 305  $\mu\text{sec}$  (see FIG. 2).

5

#### Comparative Example 2

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that  $\text{Er}^{+3}$  was used instead of  $\text{Pr}^{+3}$ .  $\text{Er}_2\text{S}_3$  was used as the source of  $\text{Er}^{+3}$ . Then, the optical fiber was cut into a disc 10 shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level showed a maximum light absorption.

15 As a result, the fluorescence emission at a wavelength of 1.55  $\mu\text{m}$ , which was caused by electron transition of  $\text{Er}^{+3}$  from the  $^4\text{I}_{13/2}$  level to  $^4\text{I}_{15/2}$  level, was observed (see FIG. 5), and the fluorescence lifetime at the  $^4\text{I}_{11/2}$  and  $^4\text{I}_{13/2}$  levels was 2100  $\mu\text{sec}$  and 3400  $\mu\text{sec}$ , respectively (see FIG. 2)

20

#### Example 1

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that  $\text{Er}^{+3}$  was further added in the amount of 300 ppm together with 300 ppm of  $\text{Pr}^{+3}$ . Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and 25 polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level showed a maximum light absorption.

As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by 30 electron transition from  $^1\text{G}_4$  level to  $^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  $^4\text{I}_{13/2}$  level to  $^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see

FIG. 1 (a)). The intensify of fluorescence was increased at each wavelength compared to that of Comparative Examples 1-2. Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  $^1\text{G}_4$  level was 605  $\mu\text{sec}$ , and the fluorescence lifetime of  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  and  $^4\text{I}_{13/2}$  levels was 824  $\mu\text{sec}$  and 3120  $\mu\text{sec}$ , 5 respectively (see FIG. 2).

According to Example 1, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$  was due to the effective energy transfer indicated by "b". Thus, the optical fiber obtained in Example 1 can be used at wavelengths of both 1.3  $\mu\text{m}$  and 1.55 10  $\mu\text{m}$ .

Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  $^1\text{G}_4$  level was markedly elongated to 605  $\mu\text{sec}$  compared to Comparative Example 1, and the light amplification efficiency at the wavelength of 1.3  $\mu\text{m}$  was further improved by adding both  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$ . However, the fluorescence lifetime of  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  15 level was 3120  $\mu\text{sec}$ , which is lower than in Comparative Example 2, thus lowering light amplification efficiency. This is due to the energy transfer indicated by "e".

### Example 2

20 An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 500 ppm of  $\text{Er}^{+3}$  was further added together with 300 ppm of  $\text{Pr}^{+3}$ . Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant 25 were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level showed a maximum light absorption.

As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by 30 electron transition from  $^1\text{G}_4$  level to  $^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  $^4\text{I}_{13/2}$  level to  $^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see FIG. 1 (b)). The intensify of fluorescence was increased at each wavelength

compared to that of the Comparative Examples 1-2. Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  $^1\text{G}_4$  level was 760  $\mu\text{sec}$ , and the fluorescent lifetime of  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  and  $^4\text{I}_{13/2}$  levels was 1740  $\mu\text{sec}$  and 2910  $\mu\text{sec}$ , respectively (see FIG. 2).

5 According to Example 2, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$  was due to the effective energy transfer indicated by "b". Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  $^1\text{G}_4$  level was markedly elongated to 760  $\mu\text{sec}$  compared to Comparative Example 1 and Example 1, and the fluorescence 10 lifetime of  $\text{Er}^{+3}$  at the  $^4\text{I}_{13/2}$  level was decreased to 2910  $\mu\text{sec}$ , compared to Comparative Example 2 and Example 1.

From the above result, it can be understood that the energy transfer indicated by "b" and "e" occur more effectively as the content of  $\text{Er}^{+3}$  increases. However, the fluorescence lifetime of  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level was 15 increased to 1740  $\mu\text{sec}$ , compared to Example 1. As a result, it was concluded that as  $\text{Er}^{+3}$ , which is not involved in the energy transfer indicated by "b", increases, the energy transfer degree in the direction indicated by "b" decreases.

20 Example 3

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 700 ppm of  $\text{Er}^{+3}$  was further added together with 300 ppm of  $\text{Pr}^{+3}$ . Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. 25 Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level showed a maximum light absorption.

As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by 30 electron transition from  $^1\text{G}_4$  level to  $^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  $^4\text{I}_{13/2}$  level to  $^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see

FIG. 1 (c)). The intensify of fluorescence was increased at each wavelength compared to that of Examples 1-2. Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level was 769  $\mu\text{sec}$ , and the fluorescence lifetime of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels was 1760  $\mu\text{sec}$  and 2920  $\mu\text{sec}$ , respectively (see FIG. 2).

5 According to Example 3, as the content of  $\text{Er}^{+3}$  increased, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level was slightly increased. This was due to an increase in energy transfer indicated by "b" shown in FIG. 3. However, because  $\text{Er}^{+3}$  was contributed for elongating the fluorescence lifetime at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels, the ratio of  $\text{Er}^{+3}$  associated with the 10 energy transfer indicated by "b" and "e" was decreased, thus resulting in a slight increase in fluorescence lifetime of  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level. That is, the light amplification efficiency at the wavelength of 1.55  $\mu\text{m}$  showed a tendency to increases with an increase in the fluorescence lifetime of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{13/2}$  level.

15

#### Example 4

An optical fiber was manufactured in the same manner as in Comparative Example 1 except that 1000 ppm of  $\text{Er}^{+3}$  was further added together with 300 ppm of  $\text{Pr}^{+3}$ . Then, the optical fiber was cut into a disc 20 shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  level showed a maximum light absorption.

25 As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by electron transition from  ${}^1\text{G}_4$  level to  ${}^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  ${}^4\text{I}_{13/2}$  level to  ${}^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see FIG. 1 (d)). The intensify of fluorescence was increased at each wavelength 30 compared to that of Examples 1-3. Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level was 881  $\mu\text{sec}$ , and the fluorescent lifetime of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels was 2030  $\mu\text{sec}$  and 3340  $\mu\text{sec}$ , respectively (see FIG. 2).

According to Example 4, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelength of 1.3  $\mu\text{m}$  by  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level, and at the wavelength of 1.55  $\mu\text{m}$  by  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{13/2}$  level, was due to effective energy transfer indicated by "b". Also, the fluorescence lifetime of 5  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels showed the maximum levels. Thus, it can be understood that the mixing ratio of  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$  in this embodiment shows the maximum light amplification efficiency at both 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ .

10 **Example 5**

An optical fiber was manufactured by the same manner as in Comparative Example 1 except that 1500 ppm of  $\text{Er}^{+3}$  was further added together with 300 ppm of  $\text{Pr}^{+3}$ . Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. 15 Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  level showed a maximum light absorption.

As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by 20 electron transition from  ${}^1\text{G}_4$  level to  ${}^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  ${}^4\text{I}_{13/2}$  level to  ${}^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see FIG. 1 (e)). The intensify of fluorescence was saturated, i.e., at the maximum level, at each wavelength. Also, the fluorescence lifetime of  $\text{Pr}^{+3}$  25 at the  ${}^1\text{G}_4$  level was 794  $\mu\text{sec}$ , and the fluorescence lifetime of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels was 1870  $\mu\text{sec}$  and 3240  $\mu\text{sec}$ , respectively (see FIG. 2).

According to Example 5, as shown in FIG. 3, the simultaneous fluorescence emission at the wavelength of 1.3  $\mu\text{m}$  by  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level and at the wavelength of 1.55  $\mu\text{m}$  by  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{13/2}$  level was due to 30 effective energy transfer indicated by "b". The fluorescence lifetime of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  and  ${}^4\text{I}_{13/2}$  levels was slightly decreased compared to Example 4, because the energy transfer indicated by "b" and "e" were saturated.

Example 6

Ge, Ga and S having a purity of 99.999% or more, were weighted in an atomic ratio of 25:5:70 in a glove box where the content of hydroxy (OH) group and oxygen was maintained to be 10 ppm or less, and 300 ppm of 5  $\text{Pr}^{+3}$  and 300 ppm of  $\text{Er}^{+3}$  were added.

After filling a  $\text{SiO}_2$  test tube with the composition, the test tube was left under a vacuum condition of 0.1 mTorr for a predetermined period of time. Then, the test tube was made airtight by sealing it with an oxy-propane flame.

10 Following this, the test tube was put into a rocking furnace such that the composition comprised in the test tube was completely mixed, and the resultant was kept at 950°C for 12 hours. Then, the test tube was quenched in air, and heated in a furnace which was set at 260°C for 1 hour. After the heating process, the test tube was slowly cooled to room temperature and 15 broken into pieces, resulting in an optical fiber formed of a  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$  doped sulfide glass of  $\text{Ge}_{25}\text{Ga}_5\text{S}_{70}$  in which the amount of lattice vibration relaxation was slight.

20 The optical fiber was cut into a disc shape (having a diameter of 10 mm and a thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  $^4\text{I}_{11/2}$  level showed a maximum light absorption.

25 As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by electron transition from  $^1\text{G}_4$  level to  $^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  $^4\text{I}_{13/2}$  level to  $^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see FIG. 6 (a)).

30 According to Example 6, it can be understood that both a Ge-Ga-S glass doped with  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$  and a Ge-As-Ga-S glass doped with  $\text{Pr}^{+3}$  and  $\text{Er}^{+3}$  can be used as a material of an optical amplifier which can be used at both 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ .

Example 7

An optical fiber was manufactured in the same manner as in Example 6 except that the amount of  $\text{Pr}^{+3}$  was increased to 500 ppm. Then, the optical fiber was cut into a disc shape (having a diameter of 10 mm and a 5 thickness of 3 mm) and polished. Then, the fluorescence spectrum and fluorescence lifetime of the resultant were measured using a laser beam having a wavelength of 980 nm as a source of light excitation. At this wavelength,  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{11/2}$  level showed a maximum light absorption.

As a result, the fluorescence emission of  $\text{Pr}^{+3}$ , which was caused by 10 electron transition from  ${}^1\text{G}_4$  level to  ${}^3\text{H}_5$  level and that of  $\text{Er}^{+3}$ , which was caused by electron transition from  ${}^4\text{I}_{13/2}$  level to  ${}^4\text{I}_{15/2}$  level were observed simultaneously at the wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , respectively (see FIG. 6 (b)). Also, as the amount of  $\text{Pr}^{+3}$  was increased, energy transfer in directions indicated by "b" and "e" in FIG. 3 increased. As a result, the 15 fluorescence intensity of  $\text{Pr}^{+3}$  at the  ${}^1\text{G}_4$  level increased at the wavelength of 1.3  $\mu\text{m}$ , whereas that of  $\text{Er}^{+3}$  at the  ${}^4\text{I}_{13/2}$  level decreased at the wavelength of 1.55  $\mu\text{m}$ . However, the rate at which the fluorescence intensity increases at 1.3  $\mu\text{m}$  is slower than the rate at which the fluorescence intensity decreases at 1.55  $\mu\text{m}$ , and thus it can be inferred that the energy transfer 20 indicated by "e" is more rapid than that indicated by "b".

Summing up the results, it can be understood that increasing the concentration of  $\text{Pr}^{+3}$  is undesirable.

Industrial Applicability

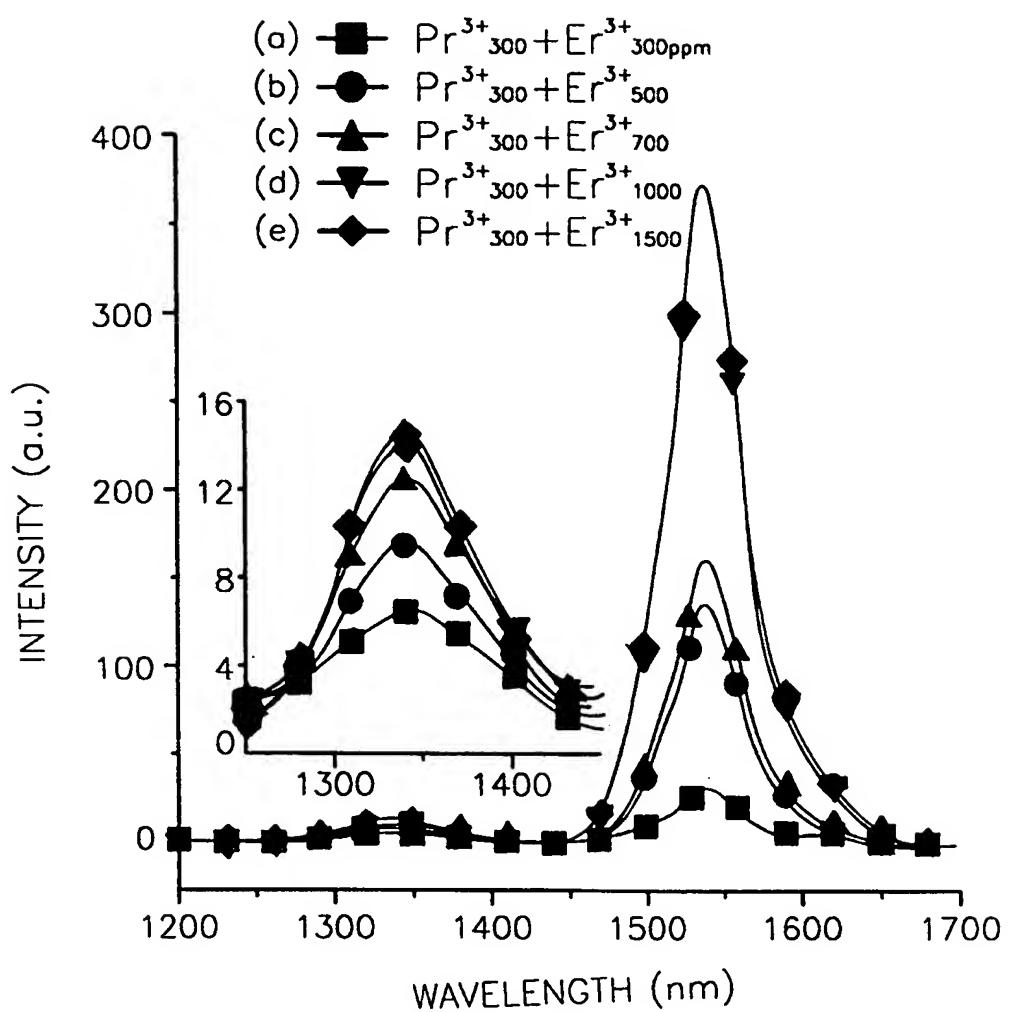
25 As described above, the optical fiber used in an optical amplifier according to the present invention can be applied to both wavelengths of 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$ , improving light amplification efficiency compared to a conventional optical fiber amplifier containing only  $\text{Pr}^{+3}$ .

What is claimed is:

1. An optical fiber for an optical amplifier, which is formed by doping glass with rare-earth ions, wherein both praseodymium ions ( $Pr^{+3}$ ) and erbium ions ( $Er^{+3}$ ) are used as the rare-earth ions, and the glass is a 5 fluoride glass or a sulfide glass.
2. The optical fiber of claim 1, wherein the sulfide glass is a germanium-arsenic-gallium-sulfide (Ge-As-Ga-S) glass or a Ge-As-S glass.
- 10 3. The optical fiber of claim 1, wherein the fluoride glass is a ZBLAN glass containing zirconium (Zr), barium (Ba), lanthanum (La), aluminum (Al) and sodium (Na).
- 15 4. The optical fiber of claim 1, wherein the mixing weight ratio of  $Pr^{+3}$  to  $Er^{+3}$  is between 1:1 and 1:3.
5. The optical fiber of claim 1, wherein a laser having a wavelength capable of absorbing  $Er^{+3}$  is used as a light source for exciting the optical fiber.
- 20 6. The optical fiber of claim 1, wherein the content of  $Pr^{+3}$  is 100~1000 ppm and the content of  $Er^{+3}$  is 100~5000 ppm.

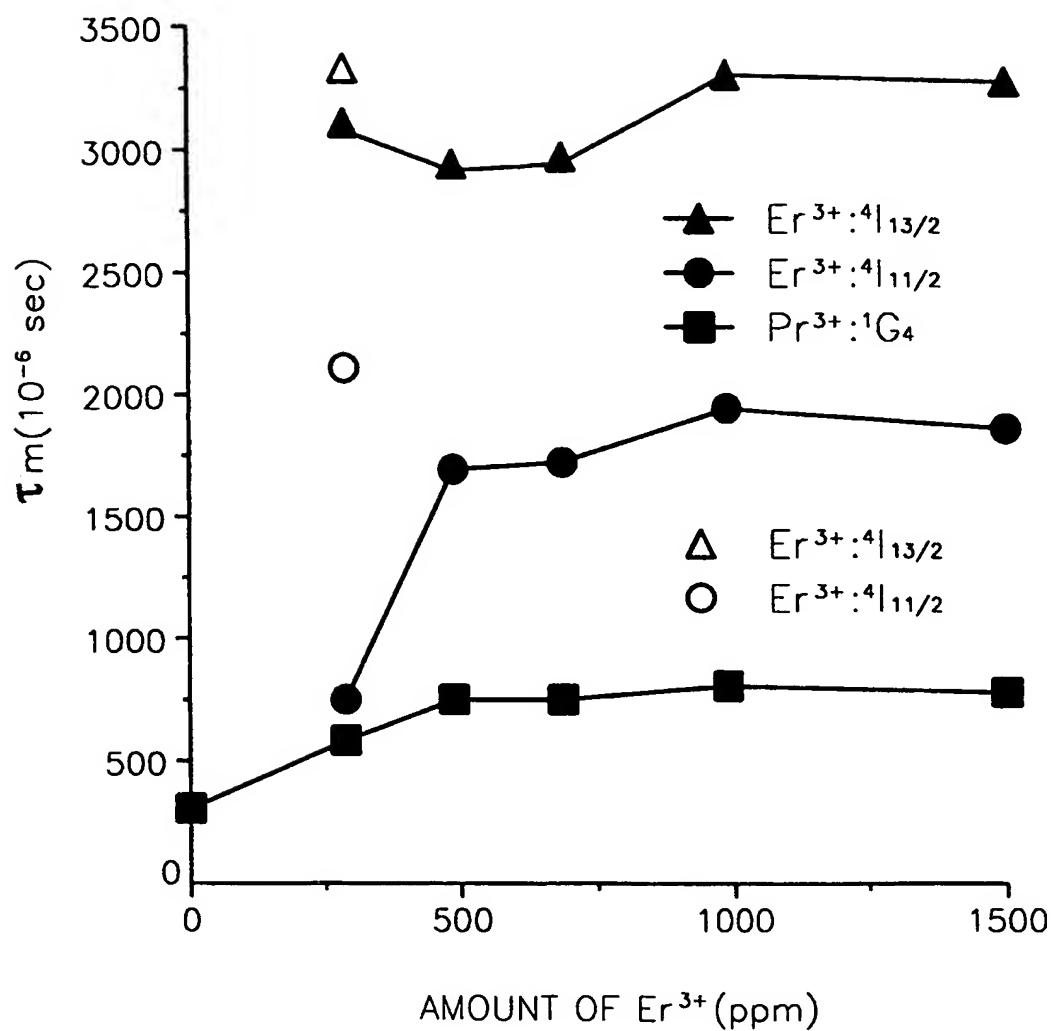
1/6

FIG. 1



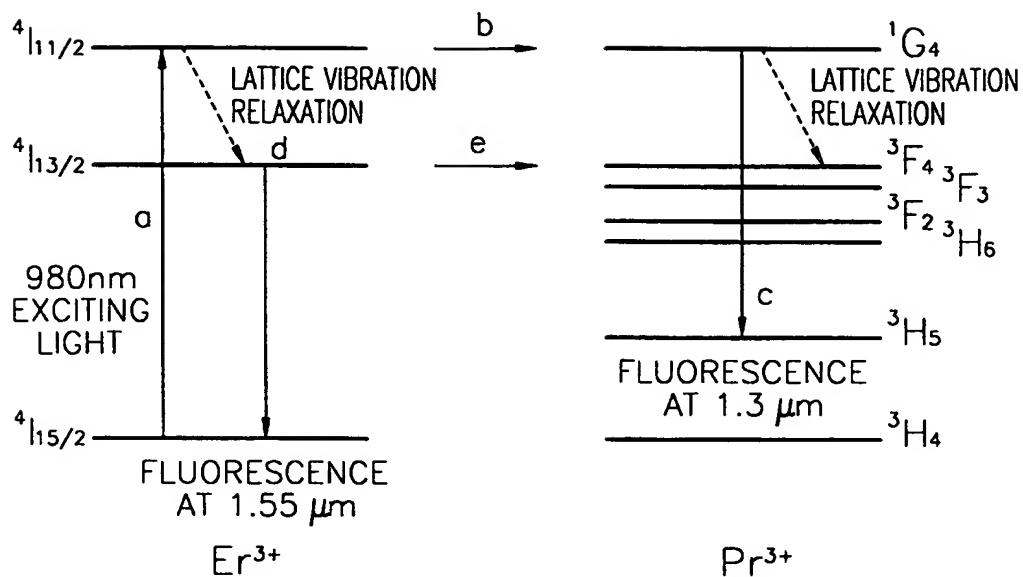
2/6

FIG. 2



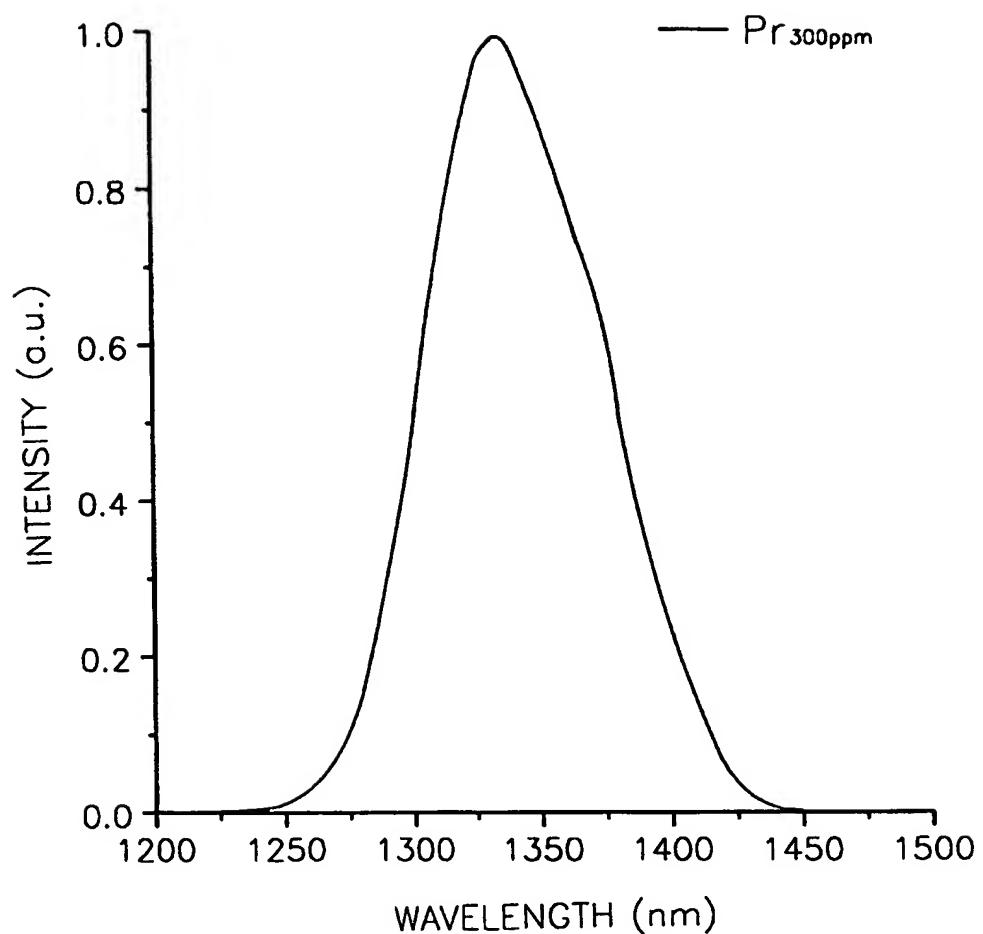
3/6

FIG. 3



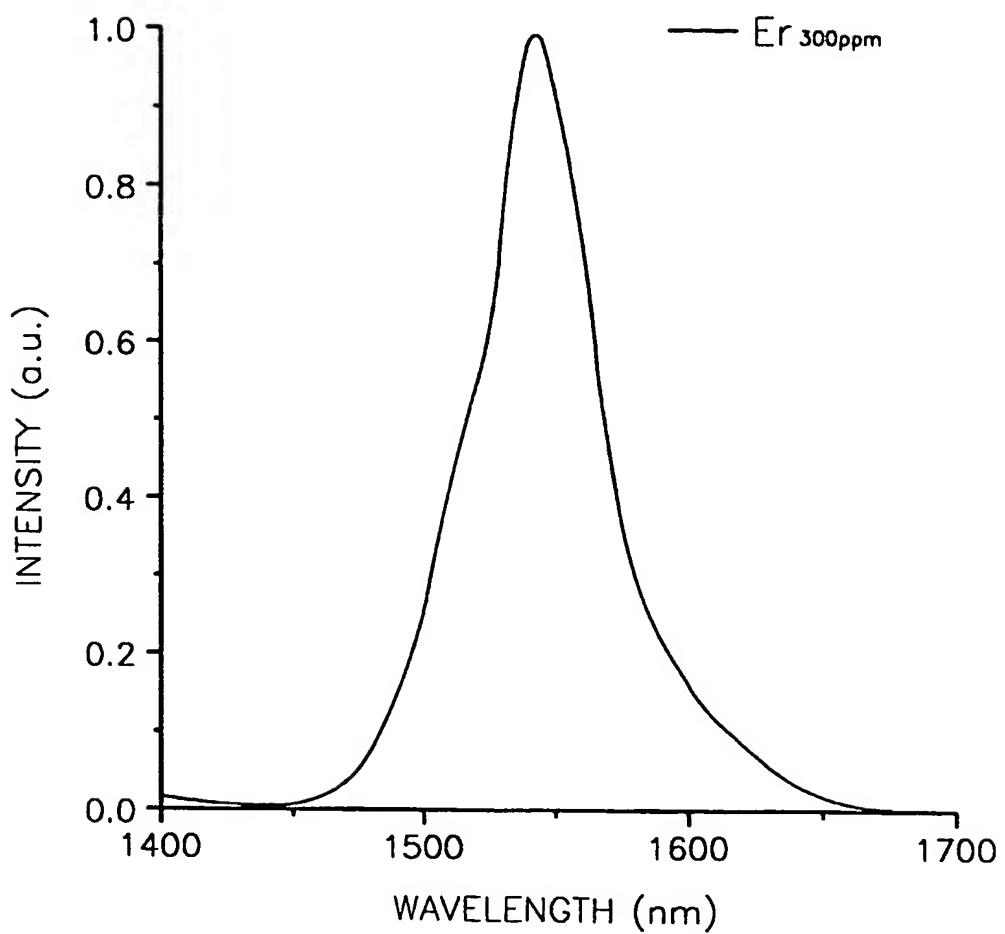
4/6

FIG. 4



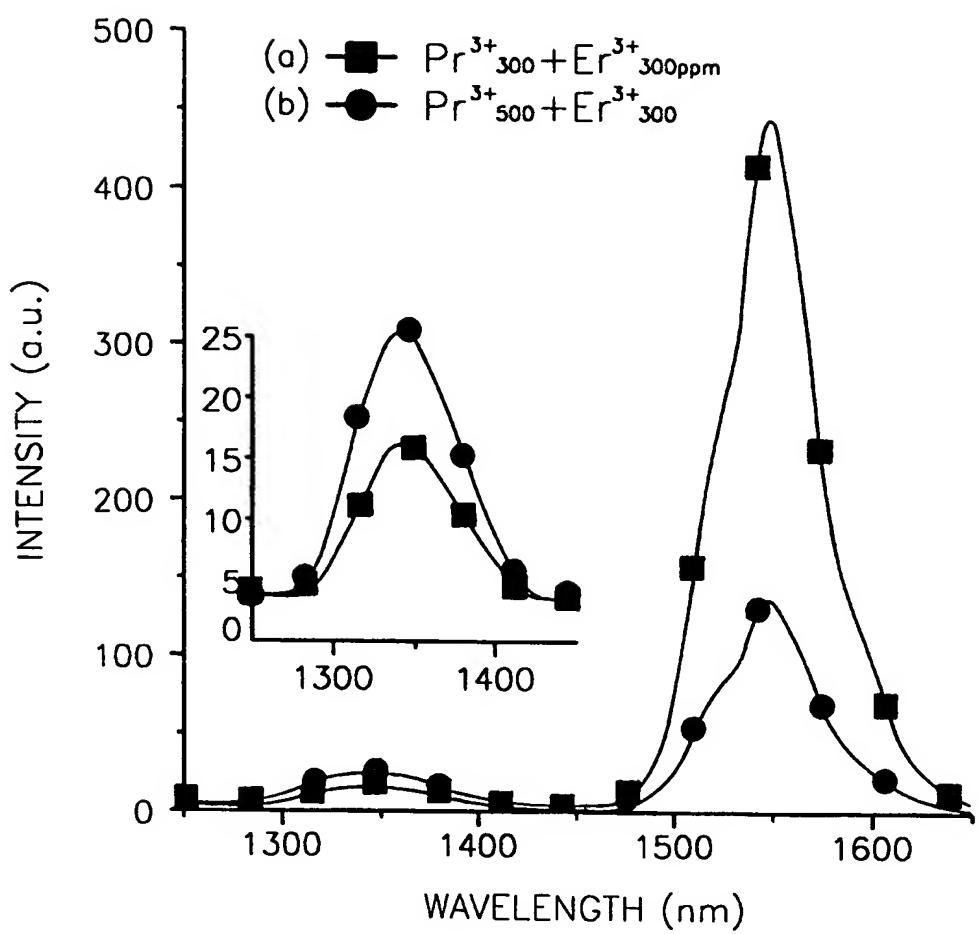
5/6

FIG. 5



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FIG. 6



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/KR 99/00609

A. CLASSIFICATION OF SUBJECT MATTER		
IPC <sup>7</sup> : C 03 C 13/04; H 01 S 3/06		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
IPC <sup>7</sup> : C 03 C; H 01 S		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
WPI, EPODOC, PAJ		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5486947 A (OHISHI et al.), 23 January 1996 (23.01.96), abstract; column 2, line 45 - column 3, line 58; example 29.	1,3-6
A	EP 0511069 A1 (ALCATEL N.V.), 28 October 1992 (28.10.92), claim 1; column 2, lines 1-9.	1,3
A	JP 08-104533 A (NIPPON TELEGRAPH), 23 April 1996 (23.04.96), (abstract), [online] [retrieved on 24 November 1999 (24.11.99)]. Retrieved from: EPO PAJ Database.	1
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<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: ..A" document defining the general state of the art which is not considered to be of particular relevance ..E" earlier application or patent but published on or after the international filing date ..L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) ..O" document referring to an oral disclosure, use, exhibition or other means ..P" document published prior to the international filing date but later than the priority date claimed		
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Date of the actual completion of the international search		Date of mailing of the international search report
24 November 1999 (24.11.99)		18 February 2000 (18.02.00)
Name and mailing address of the ISA/AT Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/200		Authorized officer  Hauswirth  Telephone No. 1/53424/136

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

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